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the other predominating calcium phosphate with much organic matter. The two groups, although they may be alike structurally, are physiologically quite dissimilar, the chemical reactions involved in building the shells being of two different orders. Such a distinction ought to be significant to biologists, and it is for them to determine what it means. Geologically, however, we can see that the phosphatic brachiopods have probably played some part in the formation of phosphatic sediments, a function which is shared by vertebrate animals and some crustaceans.

¹ Published by permission of the Director of the U. S. Geological Survey.

² Sharples, S. P., *Amer. J. Sci.*, ser. 3, 1, 168 (1871).

³ Kunckell, F., *J. prakt. Chem.*, ser. 2, 59, 102 (1899).

⁴ Schmelck, L., *Norske Nordhavs Expedition*, No. 28, p. 129 (1901).

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ON THE OCCURRENCE OF THE LINE 4686 A AND THE RELATED SERIES OF LINES IN THE SPECTRA OF THE PLANETARY NEBULAE

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The line 4686 A and the related series of lines known as the ζ Puppis series, or 'sharp series' of hydrogen, were first observed in the spectra of the heavenly bodies. In 1912 Fowler succeeded in exciting them in a laboratory source.¹ More recently they have played an important rôle in certain theories of the constitution of the atom.²

The lines in question exist in the spectra of the planetary nebulae, and a number of facts concerning their occurrence have been brought out in the course of an investigation, now being undertaken, of these spectra. This study, while not yet complete, has led to some tentative generalizations on the behavior of certain of the nebular lines, prominent among them the one at 4686, and it may add to the significance of some of the observations of this line if a brief account is given of these. In what follows I shall attempt to state in general terms what appear to me to be the most significant facts gathered from an examination of about a dozen planetary nebulae, and shall make only occasional references to individual objects. A detailed account of all of the observations will appear on the completion of the work. The conclusions arrived at here are, of course, subject to revision in the light of additional data.

In another publication reference has been made to the fact that the nuclei of the planetary nebulae are in general Class O, or to use an older term, Wolf-Rayet stars.³ The inquiry into the relationship between the spectra of the nebulae and their nuclei has necessitated a study of the distribution of light in the nebulae, line by line. This has been pursued by various means, only one of which need be referred to here. If the slit of the spectroscope be placed across the image of one of these usually symmetrical nebulae, those lines which are emitted throughout its full extent will be longer than those given out say only close to the center. In this way the length of a line may be taken as the measure of the extent of its occurrence in the source, just as is the case in laboratory studies of the arc, spark and other terrestrial sources.

It has been found that in the majority of cases the nebulae are not homogeneous,⁴ that is, lines observed in the above described manner have different lengths, and in general there is a certain order of length for the different lines. Selecting a few from the sixty or more nebular lines we may say that 4686 is always among the shortest, followed by the lines of helium, 'nebulium' and hydrogen in the order of length. An interpretation of this phenomenon on the assumption that the nebulae are in the process of condensation into stars is that the lines shrink into the nucleus in this order. We have examples of nebulae in many stages of the process. The present purpose however is not to enter into a speculative discussion of the development of stars, but to sketch the behavior of the line 4686 and the members of the related series.

The line 4686 is found in two forms: (a) as a narrow line in the nebulosity of some of these objects, and (b) as a broad band confined to the nuclei of certain others. Its occurrence in both forms in the same nebula is rare, one case only of this sort having been observed.

(a) *Occurring in the first form.* The line presents the appearance of a monochromatic radiation, under the strongest dispersion used, that of three dense prisms. It is generally (perhaps always) accompanied by very faint ζ *Puppis* lines (5411, 4541, 4200) of a similar character. It is to be looked for in those nebulae in which the lines 5007 and 4959 have their greatest strength relatively to the hydrogen lines. A case in point is the nebula N. G. C. 7027, the brightest known planetary. In this object the position of the line, derived from four photographs secured with a three prism spectrograph, is 4685.93, (R), a quantity in satisfactory agreement with Fowler's laboratory determination of 4685.98 (Rowland). The wave-lengths of the three related lines were measured with a dispersion of one prism. They are 5411.4, 4541.7, and 4202.2. The last value is not very trustworthy and all three are sub-

ject to revision with further observation. The agreement with the values calculated by theory: 5411.74, 4541.79, and 4200.02, is good. N. G. C. 7027 appears to be an unusually homogeneous nebula, 4686 being probably coextensive with the helium and hydrogen lines.

In addition to the ζ *Puppis* series of lines, another series lying in the ultraviolet was found by Fowler to be associated with 4686. The first member of this series, 3203, has been searched for with a quartz spectrograph attached to the Crossley reflector. It could not be photographed with a prolonged exposure, but this does not prove its nonexistence, as the reflectivity of silver is very low at 3200. It should be looked for with more suitable apparatus.

(b) *Occurrence as a nucleus line.* As has been remarked, the line when confined to the nucleus is broadened out into a band, which is frequently bordered on the edge of shorter wave-length by a broad dark line. The maximum of this band is commonly displaced toward the red end of the spectrum, the amount of the shift being of the order of an angstrom. The lines of the ζ *Puppis* series are present, in planetary nuclei, in some instances as bright and in others as dark bands. In this respect they parallel their behavior in Class O stars in general, as described by the observers of the Harvard College Observatory.⁵ As an example we may cite the nebula B. D. + 30°3639. The nucleus of this object is a well known Class O star, and contains numerous bright bands in addition to that at 4686. Nearly all of these are of the same width, about 10 Å. A very few bands have widths of about a quarter of this amount, and among them are the members of the ζ *Puppis* series. These, with 4686, are bordered on the violet edge by broad dark lines.

In only one instance has 4686 been found to exist in both nebula and nucleus. In N. G. C. 2392 the narrow nebular line contains a knot where the continuous spectrum of the nucleus crosses it. From the apparent rarity of this condition it seems probable that the transition from one form of radiation to the other, in any progressive change which may be going on in these objects, takes place with comparative rapidity, once it has begun.

It is an unsettled question among physicists whether the lines here discussed are due to hydrogen or helium. On this phase of the matter the nebulae appear to shed no light, as they afford no indication that the radiations belong to either of these elements. Fowler however noticed certain peculiarities of their localization in vacuum tubes, and it is possible that their behavior in this respect in the planetary nebulae may lead to some understanding of the conditions obtaining in these objects.

The interesting theory of radiation proposed by Bohr, to which reference has already been made, predicts lines separated by about two angstroms from the members of the Balmer series. Their verification in the spectra of the nebulae would be a matter of great importance, but the problem presents unusual difficulties which I have not yet been able to overcome. It is possible that future efforts will meet with greater success.

An attempt has recently been made, by an excellent observer, to classify the nebulae on the basis of the intensity of 4686. The line is common to both the nebulae and the Class O stars, and in the proposed system of classification it is assumed that the brighter a line in a nebula the closer the latter approaches to the stellar type. While I believe that the line in question, with others, will eventually serve as the basis of such a classification, I am strongly of the opinion that the matter of the intensity of the line alone affords no clue to the position of the spectrum in the scale of development unless indeed it be in a sense entirely opposite to the one suggested. It is not until the line settles into the nucleus, and is practically eliminated from the nebula proper, that the Class O stage is approached. In such objects as N. G. C. 2d Index 418, N. G. C. 6826 and N. G. C. 6572, which have Class O nuclei, the line is confined to the nucleus, and is a very inconspicuous affair. In general the more prominent this line in the spectrum of a nebula the further removed is the object from the stellar stage. The nebula N. G. C. 7027 apparently has no Class O characteristics, but 4686 is among its strongest lines.

¹ *London, Mon. Not. R. Ast. Soc.*, **73**, 62 (1913); E. J. Evans, *Nature, London*, **92**, 5 (1913).

² N. Bohr, *Phil. Mag., London*, ser. 6, **26**, 1 and 476 (1913); A. Fowler, *London, Phil. Trans. R. Soc.*, **214**, 225 (1914).

³ *Astrophys. J.*, December, 1914.

⁴ A number of cases of non-homogeneity of nebulae have been reported by previous observers. Campbell found the hydrogen lines relatively strong in the outer parts of the *Orion* and *Trifid* nebulae and also of N. G. C. 2d Index 418 = S. D. M. - 12° 1172. See also Hartmann, *Astrophys. J.*, **21**, 389 (1905). See also Burns's observations of the Ring nebula, *Lick Obs. Bul.*, **6**, 92 (1910). Wolf has observed the Ring nebula in *Lyra*, by a method identical with that described in this paper, and finds 4686 to be a short line. *Sitz. Heid. Akad. Wiss.*, **27**, 1 (1911).

⁵ Miss A. J. Cannon, *Ann. Obs. Harvard Coll.*, **56**, 66 (1912).